Flow Field Characteristic Analysis for Auxiliary Ventilation during Different Excavation Stages in Coal Mine

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Keywords: Auxiliary Ventilation, Underground Coal Mining, Different Excavation Stages, Velocity and Pressure Field, Numerical Simulation.

Abstract. Different ventilation modes and layout parameters in coal mine have a great influence on the flow field distribution. Based on the analysis of the key factors of ventilation airflow in excavation roadway, the ventilation and gas coupling flow field simulation was established by finite element method in this paper, and the ANSYS/FLOTRAN software was used to simulate the airflow velocity, pressure field distributions during different stages of excavation. The results show that the airflow speed is small above the horizontal line of the outlet near the roof, which forms a higher gas concentration. Along with the advance of excavation, the pressure in heading face increases, velocity vortex area under the outlet moves toward the heading face, and high gas concentration area moves to the entrance of the roadway. The results of the study can provide theoretical basis for reasonable layout and parameter optimization of the auxiliary ventilation system in coal mine.

Introduction

China is the largest coal-producing country, and its gas and coal dust explosion in the number and intensity is highest in the world. With the scale and depth of mining increased, the occurrence of coal dust and gas explosion risk also increases. According to recent statistics, the explosion occurred in the tunneling process accounted for 60-70\% of the total mine gas and coal dust explosion [1]. The excavation roadway in a coal mine is a single entry, and the ventilation circuit is not complete, the dilution and elimination of dust depend on the local ventilation system, which consists of local fans and air pipes. Therefore, with the expansion of the scale of coal mining, it requires better local ventilation conditions in heading face [2,3]. There are many methods to predict the ventilation and gas distribution along the heading face, such as the method of mining statistics, Simple arithmetic, coal gas content calculation and sub-source basis from the gas generated by the mechanism, etc. [4-7]. Besides, CFD software are widely used to simulate the airflow and gas distribution in the excavation roadway.

It has long been realized that the restricted jet structural parameters in the roadway, different ventilation modes, the location of the fan’s air pipe and other factors have a great impact on flow field [8]. Many domestic and foreign scholars have some qualitative understanding towards the flow field and gas transmission in the heading face [9,10], but the ventilation flow field of research in heading face mainly confined to a single form of radio jets [11]. It is difficult to describe the actual condition of the flow field accurately. In order to reveal and explain gas flow patterns in heading face at different stages of excavation, aiming
at the actual situation of the heading ventilation layout in Xiashijie coal mine, ANSYS / FLOTRAN software is used in this paper to simulate, analyze and predict the underground ventilation status together with the gas pressure and velocity field under different stages of excavation. Then the regularities of gas concentration distribution would be obtained, which can provide a theoretical basis for the prediction of different stages of excavation in coal mine ventilation and optimize the ventilation system.

**Modelling of Airflow Field Simulation for Auxiliary Ventilation**

**Overview of the Coal Mine Ventilation System.** According to "Coal Mine Safety Handbook", "Air Safety" and other relevant literatures [12], the local ventilation arrangement in heading face is shown in Fig. 1.

![Figure 1. Geometry position of the heading face with local fan.](image)

The technical standard stipulates that the distance between the local ventilation fan and the corner of the heading face shall not exceed 10m. The effective distance between air pipe outlet and the end of the tunnel is determined by the forced ventilation formula (the following Eq. 1), its value can not be greater than 5m.

\[
L_s \leq 4 \sim 5 \sqrt{S}.
\]  

(1)

Where \(L_s\) is the maximum distance between the outlet to the reverse jet (ie, the total length of the expansion and contraction of the segment), this is called the effective range of the jet, \(S\) is the cross-section area of roadway.

**Geometry Model.** The cross-section of the upper half roadway is a semicircle, while lower half is a rectangle, referring to Xiashijie coal mine, the cross-section of the roadway is shown in Fig. 2. The width is 4.7m, the height is 3.6m, the radius of the semicircle is 2.35m, the length are respectively 8m, 40m, 69m and 93m. The air pipe located at 3/4 of the width and height, whose radius is 0.4m. The model is shown in Fig. 3 while excavating 8m.

**Finite Element Model.** The FLUID142 unit type is selected as the three-dimensional fluid elements, using free meshing to mesh the model. Finite element model while excavating 40m is shown in Fig. 4.
Boundary Conditions and Loading Methods. According to the characteristics of the flow field in heading face, excavation work below the surface of the boundary wall used reinforcement, also known as no-slip condition. The outlet condition of the pressure boundary is 0; inlet velocity of the air pipe is 4.56m / s, the direction is negative along the Z axis; the velocity of the gas emission from roadway heading face is 0.02m / s, along positive Z direction, the side wall’s emission speed is 0.005m / s, along the X-axis positive direction and the negative direction respectively. Since the fluid medium of the ventilation fan is air, using turbulence model and the flow rate densities are set to SI units air properties AIR-IN in this simulation; setting the overall number of iterations is 40; the reference temperature is set at room temperature 20 °C, i.e.293K. The settings are shown in Table 1.

<table>
<thead>
<tr>
<th>Excavation distance(m)</th>
<th>Air suction quantity (m³/min)</th>
<th>Outlet air flow quantity (m³/min)</th>
<th>Sidewall gas emission rate (m³/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>580</td>
<td>550</td>
<td>11.28</td>
</tr>
<tr>
<td>40</td>
<td>600</td>
<td>480</td>
<td>8.64</td>
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<tr>
<td>69</td>
<td>465</td>
<td>400</td>
<td>14.904</td>
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<tr>
<td>93</td>
<td>712</td>
<td>683</td>
<td>20.088</td>
</tr>
</tbody>
</table>
Simulation on Flow Field Characteristic of Four Different Excavation Stages

Calculation and Analysis of the Velocity Field

Numerical simulation of the roadway airflow velocity distribution is shown in Fig. 5.

As can be seen in Fig. 5 (a), while excavating 8m, the gas flow rate of the outlet above and parallel to the horizontal line is high, and the speed is relatively small in the area close to the side wall and below the air pipe close to the heading face; Fig. 5 (b) illustrates the velocity field while excavating 40m in the working face. The outlet gas speed near horizontal line is large, and it is smaller near the top of the roadway; Fig. 5 (c) shows the velocity field while excavating 69m, the gas flow rate above the horizontal line at the lower end of the rearward is greater and forms a vortex, and it is smaller at the wall and the entrance of the roadway; Fig. 5 (d) shows the velocity field while excavating 93m, the gas flow velocity at the horizontal line of the air pipe and the rear end of the outlet is quite high and form large whirlpool, the speed at the horizontal line near the top and near the roadway wall at the entrance is lower. This shows that, for different excavation stages, the gas flow rate near horizontal line is large, as the excavation moving forward, there will be a whirlpool at the rear end of the air pipe driving forward together with the excavation..

Calculation and Analysis of the Pressure Field

Numerical simulation of the roadway airflow pressure distribution is shown in Fig. 6.

As can be seen in Fig. 6 (a), while excavating 8m, the gas pressure at the upper part of heading face is higher, at the entrance of the roadway is lower, and the pressure on the corner
is larger compared to other places, this is due to the presence of blind corner; as for Fig. 6 (b), the pressure near the horizontal line is the highest when excavated at 40m, and the pressure near the top of the heading face and in the corner is quite high, less pressure appears at the entrance of the roadway, and the pressure increases from the entrance to the heading face; Fig. 6 (c) shows that while excavating 69m, the gas pressure at the upper part of heading face is higher, as well as the heading face near the roof, and the pressure increases from the entrance to the heading face; as shown in Fig. 6 (d), while excavating 93m, the gas pressure at the upper part of heading face is higher, the pressure at the entrance is lower, and increases from the entrance to the heading face. Analysis of the results illustrates that, for different stages of excavation, air pressure distribution is basically the same, the larger pressure appears at the horizontal line of the air pipe, the pressure shows an increasing trend from the entrance of the roadway to the excavation working face.

Conclusions
The aim of this work is to provide a practical guide for coal mine workers who want to avoid the accidents and save energy at the same time. By analyzing the relationship among the gas concentration, velocity field and pressure field, the distribution rules of gas concentration were obtained. During different stages of excavation, the gas concentration at the horizontal line near the top is higher, the gas concentration near the side wall of the roadway is relatively high, the speed at the rear end of air pipe in the whirlpool is the lowest, with the excavation moving forward, the speed vortex region, namely the lowest gas concentration region is gradually moving forward, and the high gas concentration gradually moves to the
entrance of the roadway. According to the distribution law of the ventilation and gas obtained in this paper, during different stages of excavation, the ventilation parameters can be selected and the local ventilation layout can be optimized to improve the efficiency of the ventilation and reduce the probabilities of the overrun of gas concentration.

References


